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SATELLITE SERVICING MISSION
PRELIMINARY COST ESTIMATION MODEL

Science Applications International Corporation

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# SATELLITE SERVICING MISSION PRELIMINARY COST ESTIMATION MODEL

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# FOREWORD

This report documents the results of a brief study to develop a preliminary model for estimating the cost of a satellite servicing mission. The cost estimate generated by the model is that which would be the responsibility of a NASA Program Office in managing a satellite servicing mission. The approach taken in developing the model's structure and the estimates of the cost algorithm parameters relies heavily upon SAIC's experience with developing a Spacelab mission cost model. Therefore, estimates generated by this preliminary model should be viewed as rough order-of-magnitude indications of the cost of satellite servicing missions. If the basic approach proves useful in generating mission cost estimates, further study may be warranted to refine both the model's structure and parameter estimates.

This study was conducted between November 1986 and January 1987 under Contract NAS9-17207 (Gordon Rysavy - Technical Monitor) as part of a follow-on effort to other studies performed under this contract. The results are intended to assist NASA planners in the development of a Satellite Services System Program Plan.

Stephen Hoffman served as the Project Manager for this effort with significant contributions by Deanna Limperes, Terri Ramlose, John Soldner, and Dan Spadoni,

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## TABLES

## 1. INTRODUCTION

Despite the current uncertainties in the National Space Transportation System (NSTS) manifest resulting from the Challenger accident, the aerospace community remains interested in performing satellite servicing missions from the Shuttle. NASA also plans to perform servicing-type missions, including retrieval of the Long Duration Exposure Facility, maintenance and refurbishment of the Hubble Space Telescope, and refueling of the Gamma-Ray Observatory. Non-U.S. Government agencies are also interested in servicing-type missions such as maintenance and repair of satellite systems or exchange of material processing modules, but only if they can perceive an economic benefit to performing such a mission.

NASA is presently formulating and reviewing pricing policies for use of the NSTS which will have a direct impact on decisions of non-U.S. Government agencies regarding satellite servicing missions. If such policies appear uneconomical to the user community, the users will most likely disregard satellite servicing as a viable option.

When formulating NSTS pricing policies which deal specifically with satellite servicing-type missions, it should be of interest to NASA to be aware of the actual costs associated with performing such missions. The price NASA charges a user for a servicing mission could be significantly different from the cost incurred by NASA to implement that mission. Price could be lower than cost if the Government decides to encourage users by subsidizing missions. Conversely, price could be greater than cost if R&D is amortized. Therefore, understanding the cost of implementing a servicing mission can be an important factor in formulating a pricing policy.

As mentioned above, NASA is also undertaking several missions which require on-orbit servicing as part of normal operations. In the future, as this servicing capability becomes more widely used, NASA mission managers will be much more interested in estimating and planning for the cost of servicing as part of their overall life-cycle cost projection.

The cost model presented in this report is a preliminary methodology for determining a rough order-of-magnitude cost for implementing a satellite servicing mission. Mission implementation, in this context, encompasses all activities associated with mission design and planning, including both flight and ground crew training and systems integration (payload processing) of servicing hardware with the Shuttle. Costs not encompassed by the model are primarily those which are directly associated with a Shuttle launch (e.g., solid rocket booster refurbishment, propellants and other consumables, etc.).

A basic assumption made in developing this cost model is that a generic set of servicing hardware has been developed and flight tested, is inventoried, and is maintained by NASA. This implies that all hardware physical and functional interfaces are well known and therefore recurring CITE testing is not required. The model is thus not applicable to the first flight of a servicing hardware item.

The following sections discuss development of the cost model algorithms and examples of their use.

## 2. COST MODEL DEVELOPMENT

Since there has been no significant variety of satellite servicing missions, the cost estimation methodology and algorithms used in the model were derived from other sources. The primary source used in developing both the basic cost model structure and the algorithm parameters is SAIC's Spacelab Mission Implementation Cost (SMIC) Model, which in turn is based on the STS Integration Cost Model developed by Teledyne Brown Engineering. Other sources of information included the Spacelab Mission Implementation Cost Assessment (SMICA) Study performed by the Marshall Space Flight Center, and discussions with cognizant personnel at both the Johnson and Kennedy Space Centers.

The SMIC Model, developed for the Shuttle Payload Engineering Division (Code EM) of NASA Headquarters, provides estimates of the contractor and NASA Civil Service manpower and costs for analytical integration of Spacelab and similar Shuttle-attached payload missions. Analytical integration typically involves the following activities:

- Configuration of mission-dependent equipment to meet payload requirements;
- Verification of compatibility among payloads, mission-dependent equipment, and STS;
- Verification of safety compliance of payloads and mission-dependent equipment to STS requirements;
- Design of mission-peculiar equipment to meet integrated mission-dependent equipment/payloads requirements;
- Design of software/firmware to meet integrated payload requirements;
- Definition of ground and mission operation requirements;
- Satisfaction of minimum STS milestone and documentation requirements; and
- Delivery of integrated payload flight readiness package.

Inputs to the SMIC Model generally consist of the Spacelab configuration (e.g., long module, number of pallets) and a count of the physical and functional interfaces between the experiments and Spacelab (e.g., number of cables, lines of software, flight crew work-hours). Estimates are generated for both mission-dependent activities (e.g., design, verification) and level-of-effort activities (e.g., management, quality assurance). The final estimate also includes costs for Mission Peculiar Equipment (MPE) material, Payload Specialists, and the Payload Operations Control Center (POCC) Cadre. Contractor labor is costed at an averaged, fully burdened labor rate while Civil Service labor is taxed at the prevailing Institutional Management Service (IMS) rate.

The cost estimate from the SMIC Model represents the Code EM program manager's budget responsibility for the particular mission under study. Mission costs not included in this responsibility include experiment development and data analysis (responsibilities of the sponsoring divisions within Code E such as Astrophysics or Life Sciences), Level IV (experiment) Integration (a separate line item within the Code EM budget) and all Code M responsibilities (systems engineering and Levels III/II and I Integration). With the obvious exception of hardware development, **it has been assumed that all of these Code E and Code M activities would be pertinent to the cost of a satellite servicing mission.**

A preliminary version of the SMIC Model originally included a cost estimate for Level IV Integration activities based upon information provided by Teledyne Brown Engineering (TBE). This estimate was generated using the same set of inputs used for analytical integration. The algorithms used in determining Level IV Integration cost estimates have been included in the preliminary satellite servicing mission cost model. Similar cost algorithms are not available, however, for the Code M activities. For this preliminary analysis, results from the SMICA Study have been used to develop multiplying factors which yield the full spectrum of associated mission costs. (The SMICA Study was an in-depth examination of all costs associated with a typical Spacelab mission.) Table 1 presents the complete set of multipliers used to develop the cost algorithms for the satellite servicing mission cost model. The initial quantities are estimates of the Analytical Integration Contractor effort and the Level IV Integration Contractor effort. The multipliers yield approximations of the complete effort (contractor and Civil Service) required at both the mission management center (referred to as Mission Planning) and at the launch site center (referred to as Systems Integration).

Table 1

**FULL-COST MULTIPLIERS FOR SATELLITE SERVICING MISSIONS**

| | | |
|---|---|---|
| X = Analytical Integration Contractor Effort | | from Spacelab analogy |
| Y = Level IV Integration Contractor Effort | | from Spacelab analogy |
| Mission Planning Contractor Effort | = 1.85 X | |
| Mission Planning Civil Service Effort | = 2.05 X | |
| Systems Integration Contractor Effort | = 3.16 Y | |
| Systems Integration Civil Service Effort | = 4.69 Y | |

The generic set of servicing hardware equipment includes several items which are either purely conceptual or, at least, undergoing preliminary design study. The approach used for developing the costing functions associated with the hardware items was to assume an analogy with an equipment item or set of items from the SAIC and TBE models for Spacelab. Table 2 presents the servicing hardware and the estimated work effort analogies for the Analytical Integration Contractor and the Level IV Integration Contractor. These values are then multiplied by the factors in Table 1 to obtain the total work effort associated with implementing each hardware item on a servicing mission. For example, from Table 2 the contractor work efforts associated with implementing an RMS Arm on a mission are 930 work-hours for Analytical Integration and 446 work-hours for Level IV Integration. Using the multipliers from Table 1 yields the following estimates for the total effort involved with implementing an RMS Arm on a satellite servicing mission:

- Mission Planning Contractor Effort = 1,721 work-hours
- Mission Planning Civil Service Effort = 1,907 work-hours
- Systems Integration Contractor Effort = 1,409 work-hours
- Systems Integration Civil Service Effort = 2,092 work-hours.

Table 2

**ANALAGOUS WORK EFFORT ESTIMATES FOR SERVICING HARDWARE INTEGRATION**

| HARDWARE ITEM | CONTRACTOR WORK-HOURS | |
|---|---|---|
| | ANALYTICAL INTEGRATION | LEVEL IV INTEGRATION |
| RMS Arm | 930 | 446 |
| Manned Maneuvering Unit | 930 | 446 |
| Flight Support System (Full) | 3,401 | 2,811 |
| Flight Support System (A') | 1,541 | 1,919 |
| Satellite Holding Device | 1,365 | 948 |
| Monopropellant Tanker | 2,377 | 1,206 |
| Bipropellant Tanker | 3,307 | 1,652 |
| Satellite Checkout Equipment | 1,880 | 2,326 |
| Remote Umbilical - Electrical | 836 | 992 |
| Remote Umbilical - Fluids | 836 | 1,190 |
| Passive Cradle/Carrier | 930 | 446 |
| Ground-Based OMV | 4,070 | 1,750 |
| Orbital Replacement Unit | 339 | 407 |

In addition to the required servicing hardware, several other aspects of implementing a mission need to be taken into account. These include primarily allocations involved with planning, review, and documentation preparation associated with flying on-board the Shuttle, and with flight and ground crew training.

By analogy with the SMIC Model, a lumped allocation has been established, referred to as Mission/Shuttle Flight, which accounts for both mission-dependent and LOE activities associated with both general mission planning and satisfying STS requirements. The extent of these efforts is generally related to the degree of Shuttle services required as measured by the Shuttle Load Factor (SLF, defined in the STS Reimbursement Guide as the percent of Cargo Bay Length or payload weight capacity utilized, whichever is greater). An SLF of 75% to 100% is considered a dedicated flight, while the absolute minimum SLF is 5%, regardless of actual requirements. If the target satellite for the servicing mission is non-cooperative, for this preliminary analysis a constant allocation has been assumed to account for additional mission planning efforts. (Non-cooperative implies that the target satellite does not have on-board capabilities for performing extensive rendezvous maneuvers.)

The work effort associated with training the Mission Control Center (MCC) staff was estimated based on preliminary information obtained from JSC personnel. The MCC staff was assumed to consist of 15 Civil Service personnel and 60 contractor personnel per shift, with three operating shifts. Training for any particular mission was assumed to occur over a six-month period prior to launch with each shift in training and running simulations for two months with a training support staff of 12. The amount of this effort charged to a shared servicing mission is assumed to be a direct function of the relative amount of on-orbit mission time required for the servicing mission.

The effort associated with flight crew training is assumed to be a function of the crew work-hours on orbit. From the Spacelab analogy for reflight experiments, crew training requires 103 work-hours per hour on orbit, which is assumed as the basis for intravehicular activity (IVA). Training and proficiency efforts for routine and complex extravehicular activities (EVA) are assumed, for this preliminary analysis, to be multiples of the IVA effort.

In the event that a servicing mission requires significant use of the Shuttle General Purpose Computers, a mission planning allocation has been estimated based on 680 work-hours per 1,000 lines of software for the Spacelab Experiment Computer.

Finally, given total estimates for the mission-dependent efforts for both the mission planning and systems integration activities, the efforts associated with schedule-dependent LOE activities remain to be estimated. Determination of a mission management schedule is not included in this preliminary analysis; therefore the LOE is estimated as fixed percentages of the mission-dependent efforts. From a series of simulations run by TBE on their STS Integration Model, these percentages are 26% for mission planning LOE and 23% for systems integration LOE.

## 3. COST MODEL USAGE AND SAMPLE APPLICATIONS

The satellite servicing mission cost model developed in this preliminary study has been structured as a three-page set of worksheets. Blank worksheets are included in Appendix A. The first sheet defines the various mission-dependent cost elements of the model, the input units required for each element, and the unit allocations, in work-years, for each element. Work-hours have been converted to work-years by the full standard of 2,080 work-hours per work-year. The second sheet is simply filled in with the products of the input parameters times the unit work-year allocations for each cost element applicable to the servicing mission under study. The summations at the bottom of Sheet #2 are the total mission-dependent effort and are transferred to the top of the third sheet. Sheet #3 generates the schedule-dependent effort and total work effort.

Appropriate contractor burdened labor rates and Institutional Management Service rates can then be applied to obtain a total labor cost estimate. For example, approximate rates currently used in SAIC's SMIC Model are $56K/work-year for contractors and $15K/work-year for IMS, in Fiscal Year 1986 dollars. Estimates for material and travel costs and for Center contingency and program support can be added to the estimated labor cost. Experience in estimating the costs of Spacelab missions with a significant amount of reflight hardware indicates that these quantities amount to approximately 20% to 25% of the total labor cost.

Five example servicing mission scenarios have been developed to provide a spectrum of sample applications of the cost model. Appendix B contains summary mission descriptions and completed worksheets (#2 and #3 only) for each example mission. Shuttle Load Factors for the shared missions were determined from the reference data contained at the beginning of Appendix B. Relative mission time for the shared missions is based on an assumed nominal mission duration of five days. Flight crew IVA and EVA work-hour estimates are based on the on-orbit task descriptions with a maximum allowable EVA time of six hours. Note that Sample #3 requires a unique, customer-supplied equipment item. Since this item is not on the generic equipment list, it has been judged to be as complex to integrate as an Orbital Maneuvering Vehicle (OMV).

Table 3 summarizes the results for the five sample missions. A factor of 25% has been applied to the worksheet cost estimates to cover material, travel, and contingency.

Table 3

**SUMMARY RESULTS FOR SAMPLE APPLICATIONS**

| Mission Number | SLF (%) | Work-Years | Cost (FY86 $M) |
|---|---|---|---|
| 1 | 16 | 73.4 | 3.4 |
| 2 | 100 | 229.6 | 10.5 |
| 3 | 46 | 141.6 | 6.6 |
| 4 | 100 | 233.1 | 10.5 |
| 5 | 10 | 96.7 | 4.6 |

As a point of comparative reference, the SMICA Study examined the estimated costs of a new, dedicated Spacelab mission consisting of a short module and two pallets with nine highly complex experiments. The SMICA Study results for this reference mission were 668.6 work-years and $32M. In comparison, the example results shown in Table 3 appear to be of the proper order of magnitude, given that the satellite servicing cost model assumes reflight hardware with relatively less complex interfaces which are well understood.

## REFERENCES


"Spacelab Mission Implementation Cost Model Final Technical Report," Science Applications International Corporation, Report No. SAIC/85-1105, July 1985.

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"Analysis of Requirements for Free Flying Spacelab-Type Payloads, Vol. II - Cost Analysis," Teledyne Brown Engineering, SP81-MSFC-2565, November 1981.

"Space Transportation System Reimbursement Guide," National Aeronautics and Space Administration, JSC-11802, May 1980.

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# APPENDIX A

## SATELLITE SERVICING MISSION
## COST MODEL WORKSHEETS

The worksheets on the following pages are designed to help users ensure that they have included all factors in estimating costs for a satellite servicing mission. This is not an official NASA form, but is rather an estimate based on the best current information.

## SATELLITE SERVICING MISSION COST MODEL (SHEET 1 OF 3)

| COST ELEMENT | INPUT UNITS | UNIT WORK-YEAR ALLOCATIONS: MISSION PLANNING COTR | MISSION PLANNING NASA | SYSTEMS INTEGRATION COTR | SYSTEMS INTEGRATION NASA |
|---|---|---|---|---|---|
| 1. Mission/Shuttle Flight | SLF* | 46.4 | 51.3 | 4.6 | 6.8 |
| 2. Non-Cooperative Target | Y/N | 0.5 | 1.0 | N/A | N/A |
| 3. Relative Mission Time | % | 30.0 | 9.5 | N/A | N/A |
| 4. Flight Crew Activity | | | | | |
| a. IVA | work-hours | 0.1 | 0.1 | N/A | N/A |
| b. EVA (routine) | work-hours | 0.1 | 0.3 | N/A | N/A |
| c. EVA (complex) | work-hours | 0.2 | 0.6 | N/A | N/A |
| 5. GPC Software | 1000 lines | 0.6 | 0.7 | N/A | N/A |
| 6. RMS Arms | Number of Items | 0.8 | 0.9 | 0.7 | 1.0 |
| 7. Manned Maneuvering Unit | ↓ | 0.8 | 0.9 | 0.7 | 1.0 |
| 8. Flight Support System (Full) | ↓ | 3.0 | 3.4 | 4.3 | 6.3 |
| 9. Flight Support System (A') | ↓ | 1.4 | 1.5 | 2.9 | 4.3 |
| 10. Satellite Holding Device | ↓ | 1.2 | 1.3 | 1.4 | 2.1 |
| 11. Monopropellant Tanker | ↓ | 2.1 | 2.3 | 1.8 | 2.7 |
| 12. Bipropellant Tanker | ↓ | 2.9 | 3.3 | 2.5 | 3.7 |
| 13. Satellite Checkout Equipment | ↓ | 1.7 | 1.9 | 3.5 | 5.2 |
| 14. Remote Umbilical - Electrical | ↓ | 0.7 | 0.8 | 1.5 | 2.2 |
| 15. Remote Umbilical - Fluids | ↓ | 0.7 | 0.8 | 1.8 | 2.6 |
| 16. Passive Cradle/Carrier | ↓ | 0.8 | 0.9 | 0.7 | 1.0 |
| 17. Ground-Based OMV | ↓ | 3.6 | 4.0 | 2.7 | 3.9 |
| 18. Orbital Replacement Units | ↓ | 0.3 | 0.3 | 0.6 | 0.9 |

* Shuttle Load Factor as defined in the Space Transportation System Reimbursement Guide

## SATELLITE SERVICING MISSION COST MODEL (SHEET 2 OF 3)

| COST ELEMENT | INPUT UNITS | WORK-YEAR SUMMARIES: MISSION PLANNING COTR | MISSION PLANNING NASA | SYSTEMS INTEGRATION COTR | SYSTEMS INTEGRATION NASA |
|---|---|---|---|---|---|
| 1. Mission/Shuttle Flight | | | | | |
| 2. Non-Cooperative Target | | | | N/A | N/A |
| 3. Relative Mission Time | | | | N/A | N/A |
| 4. Flight Crew Activity | | | | | |
| a. IVA | | | | N/A | N/A |
| b. EVA (routine) | | | | N/A | N/A |
| c. EVA (complex) | | | | N/A | N/A |
| 5. GPC Software | | | | N/A | N/A |
| 6. RMS Arms | | | | | |
| 7. Manned Maneuvering Unit | | | | | |
| 8. Flight Support System (Full) | | | | | |
| 9. Flight Support System (A') | | | | | |
| 10. Satellite Holding Device | | | | | |
| 11. Monopropellant Tanker | | | | | |
| 12. Bipropellant Tanker | | | | | |
| 13. Satellite Checkout Equipment | | | | | |
| 14. Remote Umbilical - Electrical | | | | | |
| 15. Remote Umbilical - Fluids | | | | | |
| 16. Passive Cradle/Carrier | | | | | |
| 17. Ground-Based OMV | | | | | |
| 18. Orbital Replacement Units | | | | | |
| 19. Mission-Dependent Effort (Summation of Lines 1 through 18; Transfer to Sheet 3) | | | | | |

## SATELLITE SERVICING MISSION COST MODEL (SHEET 3 OF 3)

| | WORK-YEAR SUMMARIES | | | | |
|---|---|---|---|---|---|
| | MISSION PLANNING | | SYSTEMS INTEGRATION | | |
| COST ELEMENT | COTR | NASA | COTR | NASA | TOTALS |
| 19. Mission-Dependent Effort | | | | | |
| a. Mission Planning | | | N/A | N/A | |
| b. Systems Integration | N/A | N/A | | | |
| 20. Schedule-Dependent Effort | | | | | |
| a. 26% of Line 19a | | | N/A | N/A | |
| b. 23% of Line 19b | N/A | N/A | | | |
| 21. Total Work Effort (Summation of Lines 19 and 20) | | | | | |
| 22. Total Labor Cost (COTR at $56K/w-yr) (NASA IMS at $15K/w-yr) | | | | | |

# APPENDIX B

## SAMPLE MISSION DESCRIPTIONS
## AND
## COMPLETED WORKSHEETS

Completed cost estimation worksheets are included for five sample satellite servicing missions in this section. The missions included in this set cover not only the upper and lower extremes of mission complexity (and thus cost), but also are representative of typical, well-defined servicing missions. Reference data for various servicing hardware are included in Table B-1.

Table B-1

**SERVICING HARDWARE REFERENCE DATA**

| HARDWARE NAME | DRY WT (LB) | MAX WET WT (LB) | PAYLOAD BAY LENGTH (FT) |
|---|---|---|---|
| PAYLOAD BERTHING SYSTEM | 1,000 | 1,000 | 4.75 |
| FSS A' CRADLE | 3,300 | 3,300 | 1.5 |
| MONOPROPELLANT TANKER (OSCRS Ref. Design) | 2,792 | 7,792 | 3.5 |
| ORU CARRIER (Spacelab Pallet) | 2,800 | 2,800 | 10 |
| RMS | 905 | 905 | N/A |
| MFR | 102 | 102 | N/A |
| MODULE SERVICING TOOL | 70.5 | 70.5 | N/A |
| MMU | 338 | 338 | N/A |
| MMU SUPPORT STATION | 253 | 253 | N/A |
| TPAD | 106.5 | 106.5 | N/A |
| ORU CARRIER (Payload Bay Sill) | 75 (EST) | 75 (EST) | 4.3 |
| MISC. HAND TOOLS AND LIGHTING FIXTURES | 50 (APPROX) | 50 (APPROX) | N/A |

## SAMPLE MISSION #1: LARGE OBSERVATORY SPACECRAFT

- **SCENARIO:** An observatory-type spacecraft is scheduled for routine servicing including propellant resupply and exchange of a defective module. Two EVAs are required to connect and disconnect the propellant transfer line and to exchange the module. This module is of the MMS-type and is designed for on-orbit replacement. The spacecraft itself is cooperative and will use its propulsion system to meet the STS in a designated location. This is not a dedicated mission.

- **ADDITIONAL SPACECRAFT DATA**

  Vehicle Mass = 14,000 kg (Dry), 16,000 kg (Wet)

  Propellant Type = Hydrazine Monopropellant

  Propellant Mass Required = 1,500 kg (additional 500 kg held in reserve)

  Module Dimensions (LxWxH in cm) = 120 x 50 x 140

  Module Mass = 500 kg

  Mechanical Interfaces Available = RMS Grapple Fixture, FSS 3-point Latch

  Electrical Interfaces Available = 28 V DC; 1.00 kw; Standard FSS Connector

  Data/Communications Interfaces Available = 1 kbps Command Rate; Standard FSS Connector

  Fluid Interfaces Available = Fairchild Fluids Connector

  Special Considerations = Stow and Redeploy HGA and Solar Arrays

- **ON-ORBIT TIME REQUIRED** = 48 hours (2 days)

- **SERVICING HARDWARE REQUIRED**

| | Length (ft) | Weight (lbm) |
|---|---|---|
| (1) Payload Berthing System | 4.75 | 1000 |
| (2) Monopropellant Tanker | 3.5 | 7202 |
| (3) RMS | | 905 |
| (4) MFR | | 102 |
| (5) Misc. Hand Tools and Lighting Fixtures | | 50 |
| (6) ORU Carrier and Gas-type Sill Fixture | | 75 |
| (7) Module Servicing Tool (for MMS Module) | | --- |
| (8) Module | | 1103 |
| | 8.25 | 10437 |

## SAMPLE MISSION #1

## SATELLITE SERVICING MISSION COST MODEL (SHEET 2 OF 3)

| | | | WORK-YEAR SUMMARIES | | | |
|---|---|---|---|---|---|---|
| | | | MISSION PLANNING | | SYSTEMS INTEGRATION | |
| | COST ELEMENT | INPUT UNITS | COTR | NASA | COTR | NASA |
| 1. | Mission/Shuttle Flight | 16% | 7.4 | 8.2 | 0.7 | 1.1 |
| 2. | Non-Cooperative Target | N | 0.0 | 0.0 | N/A | N/A |
| 3. | Relative Mission Time | 40%* | 12.0 | 3.8 | N/A | N/A |
| 4. | Flight Crew Activity | | | | | |
| | a. IVA | 12 | 1.2 | 1.2 | N/A | N/A |
| | b. EVA (routine) | 6 | 0.6 | 1.8 | N/A | N/A |
| | c. EVA (complex) | 0 | 0.0 | 0.0 | N/A | N/A |
| 5. | GPC Software | 0 | 0.0 | 0.0 | N/A | N/A |
| 6. | RMS Arms | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 7. | Manned Maneuvering Unit | | | | | |
| 8. | Flight Support System (Full) | | | | | |
| 9. | Flight Support System (A') | | | | | |
| 10. | Satellite Holding Device | 1 | 1.2 | 1.3 | 1.4 | 2.1 |
| 11. | Monopropellant Tanker | 1 | 2.1 | 2.3 | 1.8 | 2.7 |
| 12. | Bipropellant Tanker | | | | | |
| 13. | Satellite Checkout Equipment | | | | | |
| 14. | Remote Umbilical - Electrical | | | | | |
| 15. | Remote Umbilical - Fluids | | | | | |
| 16. | Passive Cradle/Carrier | | | | | |
| 17. | Ground-Based OMV | | | | | |
| 18. | Orbital Replacement Units | 1 | 0.3 | 0.3 | 0.6 | 0.9 |
| 19. | Mission-Dependent Effort (Summation of Lines 1 through 18; Transfer to Sheet 3) | | 25.6 | 19.8 | 5.2 | 7.8 |

* 2 days out of a nominal 5-day mission

## SAMPLE MISSION #1

## SATELLITE SERVICING MISSION COST MODEL (SHEET 3 OF 3)

| COST ELEMENT | WORK-YEAR SUMMARIES: MISSION PLANNING COTR | MISSION PLANNING NASA | SYSTEMS INTEGRATION COTR | SYSTEMS INTEGRATION NASA | TOTALS |
|---|---|---|---|---|---|
| 19. Mission-Dependent Effort | | | | | |
| a. Mission Planning | 25.6 | 19.8 | N/A | N/A | |
| b. Systems Integration | N/A | N/A | 5.2 | 7.8 | |
| 20. Schedule-Dependent Effort | | | | | |
| a. 26% of Line 19a | 6.9 | 5.1 | N/A | N/A | |
| b. 23% of Line 19b | N/A | N/A | 1.2 | 1.8 | |
| 21. Total Work Effort (Summation of Lines 19 and 20) | 32.5 | 24.9 | 6.4 | 9.6 | 73.4 |
| 22. Total Labor Cost (COTR at $56K/w-yr) (NASA IMS at $15K/w-yr) | 1.8 | 0.4 | 0.4 | 0.1 | $2.7M |

## SAMPLE MISSION #2: LARGE OBSERVATORY SPACECRAFT: DEDICATED MISSION

- **SCENARIO:** An observatory-type spacecraft is scheduled for routine servicing consisting of an exchange of three modules. Two EVAs will be required to complete all activities. The spacecraft is non-cooperative requiring the STS to rendezvous at 600 km (320 nmi) altitude. The spacecraft will require a reboost to 700 km (380 nmi) altitude upon completion of servicing activities. This is a dedicated mission.

- **ADDITIONAL SPACECRAFT DATA**

Vehicle Mass = 11,600 kg (Dry)

Propulsion System = None

| Module | Dimensions (cm) | Mass (kg) |
|---|---|---|
| 1 | 58 x 30 x 28 | 24 |
| 2 | 61 x 25 x 36 | 62 |
| 3 | 91 x 91 x 221 | 318 |

Mechanical Interfaces Available = RMS Grapple Fixture, FSS 3-point Latch

Electrical Interfaces Available = 28 V DC, 1.5 kw, Standard FSS Connector

Data/Communications Interfaces Available = 1 kbps Command Rate; Standard FSS Connector

Special Considerations = Possible Manual Stow and Redeploy of HGAs and Solar Arrays

- **ON-ORBIT TIME REQUIRED** = 120 hours (5 days)

- **SERVICING HARDWARE REQUIRED**

| | Length (ft) | Weight (lbm) |
|---|---|---|
| (1) ORU Carrier (Spacelab Pallet) | | |
| (2) FSS A' Cradle | DEDICATED MISSION | |
| (3) RMS | | |
| (4) MFR | | |
| (5) Misc. Hand Tools and Lighting Fixtures | | |

## SAMPLE MISSION #2

## SATELLITE SERVICING MISSION COST MODEL (SHEET 2 OF 3)

| COST ELEMENT | INPUT UNITS | WORK-YEAR SUMMARIES: MISSION PLANNING COTR | MISSION PLANNING NASA | SYSTEMS INTEGRATION COTR | SYSTEMS INTEGRATION NASA |
|---|---|---|---|---|---|
| 1. Mission/Shuttle Flight | 100% | 46.4 | 51.3 | 4.6 | 6.8 |
| 2. Non-Cooperative Target | Y | 0.5 | 1.0 | N/A | N/A |
| 3. Relative Mission Time | 100% | 30.0 | 9.5 | N/A | N/A |
| 4. Flight Crew Activity | | | | | |
| a. IVA | 24 | 2.4 | 2.4 | N/A | N/A |
| b. EVA (routine) | 12 | 1.2 | 3.6 | N/A | N/A |
| c. EVA (complex) | 0 | 0.0 | 0.0 | N/A | N/A |
| 5. GPC Software | 0 | 0.0 | 0.0 | N/A | N/A |
| 6. RMS Arms | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 7. Manned Maneuvering Unit | | | | | |
| 8. Flight Support System (Full) | | | | | |
| 9. Flight Support System (A') | 1 | 1.4 | 1.5 | 2.9 | 4.3 |
| 10. Satellite Holding Device | | | | | |
| 11. Monopropellant Tanker | | | | | |
| 12. Bipropellant Tanker | | | | | |
| 13. Satellite Checkout Equipment | | | | | |
| 14. Remote Umbilical - Electrical | | | | | |
| 15. Remote Umbilical - Fluids | | | | | |
| 16. Passive Cradle/Carrier | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 17. Ground-Based OMV | | | | | |
| 18. Orbital Replacement Units | 3 | 0.9 | 0.9 | 1.8 | 2.7 |
| 19. Mission-Dependent Effort (Summation of Lines 1 through 18; Transfer to Sheet 3) | | 84.4 | 72.0 | 10.7 | 15.8 |

## SAMPLE MISSION #2

## SATELLITE SERVICING MISSION COST MODEL (SHEET 3 OF 3)

| | WORK-YEAR SUMMARIES | | | | |
|---|---|---|---|---|---|
| | MISSION PLANNING | | SYSTEMS INTEGRATION | | |
| COST ELEMENT | COTR | NASA | COTR | NASA | TOTALS |
| 19. Mission-Dependent Effort | | | | | |
| a. Mission Planning | 84.4 | 72.0 | N/A | N/A | |
| b. Systems Integration | N/A | N/A | 10.7 | 15.8 | |
| 20. Schedule-Dependent Effort | | | | | |
| a. 26% of Line 19a | 21.9 | 18.7 | N/A | N/A | |
| b. 23% of Line 19b | N/A | N/A | 2.5 | 3.6 | |
| 21. Total Work Effort (Summation of Lines 19 and 20) | 106.3 | 90.7 | 13.2 | 19.4 | 229.6 |
| 22. Total Labor Cost (COTR at $56K/w-yr) (NASA IMS at $15K/w-yr) | 6.0 | 1.4 | 0.7 | 0.3 | $8.4M |

## SAMPLE MISSION #3: MAN-TENDED RESEARCH FACILITY

- **SCENARIO:** A man-tended (i.e., pressurized) spacecraft is scheduled for a routine servicing flight which includes the exchange of a logistics module and IVA activities by the crew (in the Shuttle and the research facility). No EVA activity is anticipated. The "fresh" logistics module contains raw materials and other consumables. The returning logistics module contains finished products. Both modules are identical in terms of mass, dimensions, and interfaces. These modules are designed to be exchanged using only the RMS. Sufficient payload bay space must be reserved for two modules and will be utilized during the exchange process. The vehicle has no propulsion system and is thus non-cooperative. This is <u>not</u> a dedicated mission.

- **ADDITIONAL SPACECRAFT DATA**

Vehicle Mass = 15,000 kg (est)

Propulsion System = None (i.e., non-cooperative)

Logistics Module Dimensions = 14.5 ft dia. x 8.5 ft length

Logistics Module Mass (wet) = 8,000 lbm (3,600 kg)

Mechanical Interfaces Available = RMS Grapple Fixture;<br>Special Airlock Adapter

Electrical Interfaces Available = 28 V DC, 2.00 kw, Standard FSS Connector

Data/Communications Interfaces Available = Spacelab Data Bus

Special Considerations = Circular Orbit at 250 nmi (460 km)

- **ON-ORBIT TIME REQUIRED** = 96 hours (4 days)

- **SERVICING HARDWARE REQUIRED**

| | Length (ft) | Weight (lbm) |
|---|---|---|
| (1) Vehicle-unique Docking Adapter and Airlock (Customer-supplied) Mass = 800 kg (est) | 10.0 | 1764 |
| (2) RMS | --- | 905 |
| (3) Misc. Hand Tools and Lighting Fixtures | --- | 50 |
| (4) Logistics Module (Room for 2 in cargo bay) | 17.0 | 8000 |
| | 27.0 | 10719 |

**SAMPLE MISSION #3**

**SATELLITE SERVICING MISSION COST MODEL (SHEET 2 OF 3)**

| | | WORK-YEAR SUMMARIES | | | |
|---|---|---|---|---|---|
| | | MISSION PLANNING | | SYSTEMS INTEGRATION | |
| COST ELEMENT | INPUT UNITS | COTR | NASA | COTR | NASA |
| 1. Mission/Shuttle Flight | 46% | 21.3 | 23.6 | 2.1 | 3.1 |
| 2. Non-Cooperative Target | Y | 0.5 | 1.0 | N/A | N/A |
| 3. Relative Mission Time | 80% | 24.0 | 7.6 | N/A | N/A |
| 4. Flight Crew Activity | | | | | |
| a. IVA | 32 | 3.2 | 3.2 | N/A | N/A |
| b. EVA (routine) | 0 | 0.0 | 0.0 | N/A | N/A |
| c. EVA (complex) | 0 | 0.0 | 0.0 | N/A | N/A |
| 5. GPC Software | 0 | 0.0 | 0.0 | N/A | N/A |
| 6. RMS Arms | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 7. Manned Maneuvering Unit | | | | | |
| 8. Flight Support System (Full) | | | | | |
| 9. Flight Support System (A') | | | | | |
| 10. Satellite Holding Device | | | | | |
| 11. Monopropellant Tanker | | | | | |
| 12. Bipropellant Tanker | | | | | |
| 13. Satellite Checkout Equipment | | | | | |
| 14. Remote Umbilical - Electrical | | | | | |
| 15. Remote Umbilical - Fluids | | | | | |
| 16. Passive Cradle/Carrier | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 17. Ground-Based OMV | 1* | 3.6 | 4.0 | 2.7 | 3.9 |
| 18. Orbital Replacement Units | 1 | 0.3 | 0.3 | 0.6 | 0.9 |
| 19. Mission-Dependent Effort (Summation of Lines 1 through 18; Transfer to Sheet 3) | | 54.5 | 41.5 | 6.8 | 9.9 |

* This is included to account for the mission-unique hardware item (i.e., the adapter tunnel/docking fixture) and is an estimate only

## SAMPLE MISSION #3

## SATELLITE SERVICING MISSION COST MODEL (SHEET 3 OF 3)

| | WORK-YEAR SUMMARIES | | | | |
|---|---|---|---|---|---|
| | MISSION PLANNING | | SYSTEMS INTEGRATION | | |
| COST ELEMENT | COTR | NASA | COTR | NASA | TOTALS |
| 19. Mission-Dependent Effort | | | | | |
| a. Mission Planning | 54.5 | 41.5 | N/A | N/A | |
| b. Systems Integration | N/A | N/A | 6.8 | 9.9 | |
| 20. Schedule-Dependent Effort | | | | | |
| a. 26% of Line 19a | 14.2 | 10.8 | N/A | N/A | |
| b. 23% of Line 19b | N/A | N/A | 1.6 | 2.3 | |
| 21. Total Work Effort (Summation of Lines 19 and 20) | 68.7 | 52.3 | 8.4 | 12.2 | 141.6 |
| 22. Total Labor Cost (COTR at $56K/w-yr) (NASA IMS at $15K/w-yr) | 3.8 | 0.8 | 0.5 | 0.2 | $5.3M |

## SAMPLE MISSION #4: UNMANNED MPS SPACECRAFT

- **SCENARIO:** An unmanned MPS factory-type spacecraft is scheduled for routine servicing consisting of an exchange of logistics modules, the replacement of an MMS-type power control ORU and a resupply of the on-board propulsion system. Two EVAs are required to connect and disconnect the propellant transfer line and replace the ORU. The logistics module will be exchanged using the RMS. With an on-board propulsion system, the spacecraft is cooperative. This is a dedicated mission.

- **ADDITIONAL SPACECRAFT DATA**

Vehicle Mass = 9,000 kg (Wet)

Propellant Type = Hydrazine Monopropellant

Propellant Mass Required = 3,000 kg

| Module | Dimensions | Mass |
|---|---|---|
| Logistics | 14.5 ft dia. x 20 ft | 20,000 lb (9070 kg) |
| Power Control | 47" x 20" x 55" | 1,100 lb ( 500 kg) |

Mechanical Interfaces Available = RMS Grapple Fixture, FSS 3-point Latch

Electrical Interfaces Available = 28 V DC, 1.0 kw, Standard FSS Connector

Data/Communications Interfaces Available = 1 kbps Command, Standard FSS Connector

Fluid Interfaces Available = Fairchild Fluids Connector

- **ON-ORBIT TIME REQUIRED** = 96 hours (4 days)

- **SERVICING HARDWARE REQUIRED**

| | Length (ft) | Weight (lbm) |
|---|---|---|
| (1) FSS A' Cradle | | |
| (2) Monopropellant Tanker (OSCRS Ref. Design) | | |
| (3) RMS | | |
| (4) MFR | DEDICATED MISSION | |
| (5) ORU Carrier (GAS-type Sill Fixture) | | |
| (6) Module Servicing Tool | | |
| (7) Misc. Hand Tools and Lighting Fixtures | | |

## SAMPLE MISSION #4

## SATELLITE SERVICING MISSION COST MODEL (SHEET 2 OF 3)

| | | | WORK-YEAR SUMMARIES | | | |
|---|---|---|---|---|---|---|
| | | | MISSION PLANNING | | SYSTEMS INTEGRATION | |
| | COST ELEMENT | INPUT UNITS | COTR | NASA | COTR | NASA |
| 1. | Mission/Shuttle Flight | 100% | 46.4 | 51.3 | 4.6 | 6.8 |
| 2. | Non-Cooperative Target | N | 0.0 | 0.0 | N/A | N/A |
| 3. | Relative Mission Time | 100% | 30.0 | 9.5 | N/A | N/A |
| 4. | Flight Crew Activity | | | | | |
| | a. IVA | 24 | 2.4 | 2.4 | N/A | N/A |
| | b. EVA (routine) | 6 | 0.6 | 1.8 | N/A | N/A |
| | c. EVA (complex) | 0 | 0.0 | 0.0 | N/A | N/A |
| 5. | GPC Software | 0 | 0.0 | 0.0 | N/A | N/A |
| 6. | RMS Arms | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 7. | Manned Maneuvering Unit | | | | | |
| 8. | Flight Support System (Full) | | | | | |
| 9. | Flight Support System (A') | 1 | 1.4 | 1.5 | 2.9 | 4.3 |
| 10. | Satellite Holding Device | | | | | |
| 11. | Monopropellant Tanker | 1 | 2.1 | 2.3 | 1.8 | 2.7 |
| 12. | Bipropellant Tanker | | | | | |
| 13. | Satellite Checkout Equipment | | | | | |
| 14. | Remote Umbilical - Electrical | | | | | |
| 15. | Remote Umbilical - Fluids | | | | | |
| 16. | Passive Cradle/Carrier | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 17. | Ground-Based OMV | | | | | |
| 18. | Orbital Replacement Units | 2 | 0.6 | 0.6 | 1.2 | 1.8 |
| 19. | Mission-Dependent Effort (Summation of Lines 1 through 18; Transfer to Sheet 3) | | 85.1 | 71.2 | 11.9 | 17.6 |

**SAMPLE MISSION #4**

**SATELLITE SERVICING MISSION COST MODEL (SHEET 3 OF 3)**

| COST ELEMENT | WORK-YEAR SUMMARIES: MISSION PLANNING COTR | MISSION PLANNING NASA | SYSTEMS INTEGRATION COTR | SYSTEMS INTEGRATION NASA | TOTALS |
|---|---|---|---|---|---|
| 19. Mission-Dependent Effort | | | | | |
| a. Mission Planning | 85.1 | 71.2 | N/A | N/A | |
| b. Systems Integration | N/A | N/A | 11.9 | 17.6 | |
| 20. Schedule-Dependent Effort | | | | | |
| a. 26% of Line 19a | 22.1 | 18.5 | N/A | N/A | |
| b. 23% of Line 19b | N/A | N/A | 2.7 | 4.0 | |
| 21. Total Work Effort (Summation of Lines 19 and 20) | 107.2 | 89.7 | 14.6 | 21.6 | 233.1 |
| 22. Total Labor Cost (COTR at $56K/w-yr) (NASA IMS at $15K/w-yr) | 6.0 | 1.3 | 0.8 | 0.3 | $8.4M |

## SAMPLE MISSION #5: SMALL OBSERVATORY SPACECRAFT

- **SCENARIO:** A preplanned servicing mission to an uncooperative satellite will replace two defective modules. Two EVAs will be required to complete this mission: the first to retrieve the spacecraft (using an astronaut with an MMU) and the second to complete the servicing. Assume for this example that this is not a dedicated flight and that the spacecraft is at the nominal STS orbit altitude.

- **ADDITIONAL SPACECRAFT DATA**

Vehicle Mass = 5,000 lb (2,270 kg)

Propulsion System = None

| Module | Dimensions | Mass |
|---|---|---|
| ACS | 47" x 20" x 55" | 1,100 lb (500 kg) |
| Main Electronics Box | (Negligible) | 100 lb ( 45 kg) |

Mechanical Interfaces Available = RMS Grapple Fixture, FSS 3-point Latch

Electrical Interfaces Available = 28 V DC, 0.25 kw, Standard FSS Connector

Data/Communications Interfaces Available = 32 bps Command, Standard FSS Connector

- **ON-ORBIT TIME REQUIRED** = 96 hours (4 days)

- **SERVICING HARDWARE REQUIRED**

| | Length (ft) | Weight (lbm) |
|---|---|---|
| (1) FSS A' Cradle | 1.5 | 3300 |
| (2) RMS | --- | 905 |
| (3) MFR | --- | 102 |
| (4) Module Servicing Tool | --- | 70.5 |
| (5) MMU + Support Station | --- | 591 |
| (6) TPAD | | 106.5 |
| (7) Misc. Hand Tools and Lighting Fixtures | --- | 50.0 |
| (8) ACS Module | 3.9 | 1100 |
| (9) Main Electronics Box | --- | 100 |
| | 5.4 | 6325 |

## SAMPLE MISSION #5

## SATELLITE SERVICING MISSION COST MODEL (SHEET 2 OF 3)

| | | WORK-YEAR SUMMARIES | | | |
|---|---|---|---|---|---|
| | | MISSION PLANNING | | SYSTEMS INTEGRATION | |
| COST ELEMENT | INPUT UNITS | COTR | NASA | COTR | NASA |
| 1. Mission/Shuttle Flight | 10% | 4.6 | 5.1 | 0.5 | 0.7 |
| 2. Non-Cooperative Target | Y | 0.5 | 1.0 | N/A | N/A |
| 3. Relative Mission Time | 80% | 24.0 | 7.6 | N/A | N/A |
| 4. Flight Crew Activity | | | | | |
| a. IVA | 24 | 2.4 | 2.4 | N/A | N/A |
| b. EVA (routine) | 6 | 0.6 | 1.8 | N/A | N/A |
| c. EVA (complex) | 6 | 1.2 | 3.6 | N/A | N/A |
| 5. GPC Software | 0 | 0.0 | 0.0 | N/A | N/A |
| 6. RMS Arms | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 7. Manned Maneuvering Unit | 1 | 0.8 | 0.9 | 0.7 | 1.0 |
| 8. Flight Support System (Full) | | | | | |
| 9. Flight Support System (A') | 1 | 1.4 | 1.5 | 2.9 | 4.3 |
| 10. Satellite Holding Device | | | | | |
| 11. Monopropellant Tanker | | | | | |
| 12. Bipropellant Tanker | | | | | |
| 13. Satellite Checkout Equipment | | | | | |
| 14. Remote Umbilical - Electrical | | | | | |
| 15. Remote Umbilical - Fluids | | | | | |
| 16. Passive Cradle/Carrier | | | | | |
| 17. Ground-Based OMV | | | | | |
| 18. Orbital Replacement Units | 2 | 0.6 | 0.6 | 1.2 | 1.8 |
| 19. Mission-Dependent Effort (Summation of Lines 1 through 18; Transfer to Sheet 3) | | 36.9 | 25.4 | 6.0 | 8.8 |

## SAMPLE MISSION #5

## SATELLITE SERVICING MISSION COST MODEL (SHEET 3 OF 3)

| COST ELEMENT | WORK-YEAR SUMMARIES: MISSION PLANNING | | WORK-YEAR SUMMARIES: SYSTEMS INTEGRATION | | TOTALS |
|---|---|---|---|---|---|
| | COTR | NASA | COTR | NASA | |
| 19. Mission-Dependent Effort | | | | | |
| a. Mission Planning | 36.9 | 25.4 | N/A | N/A | |
| b. Systems Integration | N/A | N/A | 6.0 | 8.8 | |
| 20. Schedule-Dependent Effort | | | | | |
| a. 26% of Line 19a | 9.6 | 6.6 | N/A | N/A | |
| b. 23% of Line 19b | N/A | N/A | 1.4 | 2.0 | |
| 21. Total Work Effort (Summation of Lines 19 and 20) | 46.5 | 32.0 | 7.4 | 10.8 | 96.7 |
| 22. Total Labor Cost (COTR at $56K/w-yr) (NASA IMS at $15K/w-yr) | 2.6 | 0.5 | 0.4 | 0.2 | $3.7M |